

Introduction

This report presents findings of the 1999 water-quality survey of the Delaware River and tributaries located between the Delaware Water Gap and Trenton, NJ. The study area included 74 sampling locations along 75 miles of the Lower Delaware River (see Figure 1). The 74 sampling sites were composed of 11 Delaware River bridges (2 sites per bridge), 10 Delaware River access areas, and 42 tributaries. An additional 8 tributaries were planned for study, but remained dry throughout the study period.



Figure 1.

The Lower Delaware River divides the states of New Jersey and Pennsylvania, flowing through portions of six counties along a 77-mile reach. DRBC established 74 sampling locations for the 1999 survey.

Purposes of the survey were threefold:

- 1) Assess water-quality throughout the lower non-tidal reach of the Delaware River, and continue to develop a baseline water-quality database.
- 2) Compare bacterial data to results of the DRBC 1987 bacterial survey.
- 3) Provide a scientific basis for management plans that will maintain and enhance, where practical, existing water quality.

Design of this study was guided by the following:

- 1) To repeat the summer 1987 bacterial survey (DRBC 1988), and to compare 1987 versus 1999 results.
- 2) To cover all public river access areas, describing water-quality conditions experienced by those who swim, canoe, tube, water ski and fish the Delaware River.
- 3) To sample tributaries to the Delaware River, seeking tributary sources of bacterial and chemical pollutants.
- 4) To support the Lower Delaware River Management Plan (Lower Delaware River Wild and Scenic River Study Task Force and National Park Service, 1997). On November 19, 1999, the U.S. Senate passed S. 1296, the Lower Delaware Wild and Scenic Rivers Act. Congress passed the bill in October 2000, designating segments of the study area as a recreational river, to be managed in accordance with the Lower Delaware River Management Plan. On November 1, 2000, the President of the United States signed the Act.
- 5) To improve the data record necessary to describe the water-quality of the Lower Delaware River, sufficient for 305(b) assessments, and to extend DRBC's monitoring efforts to cover the entire non-tidal river. The Scenic Rivers Monitoring Program (SRMP), a cooperative effort of two National Park Service units and the DRBC cover the Delaware River above the Delaware Water Gap. The Lower Delaware Monitoring Program links the SRMP to existing efforts in the Delaware Estuary and Bay, providing monitoring coverage of the entire river system by filling a 75-mile gap.

On January 28, 1998, the Delaware River Basin Commission passed Resolution No. 98-2, which endorsed the Lower Delaware River Management Plan and resolved to "...take such action as it deems appropriate to implement the goals of the plan commensurate with available resources." This survey is a component of DRBC's data collection effort toward fulfillment of goals stated in the Management Plan.

The first goal of the Management Plan relates to water-quality, stating a vision to "maintain existing water-quality in the Delaware River and its tributaries from measurably degrading and improve it where practical." To do so, existing water-quality must be defined.

Analysis of the historical monitoring network revealed that the data record is insufficient to describe the status and trends of Lower Delaware River water-quality.

The bacteria portion of this study was conducted as a special, single-season survey under a larger long-term monitoring effort designed to describe the physical, chemical, and ecological quality of the Lower Delaware River corridor. DRBC and the Delaware Riverkeeper Network, under the auspices of the Delaware River Greenway Partnership, began the Lower Delaware Monitoring Program (LDMP) in 1998. In 1999, the long-term monitoring network was expanded by the DRBC.

The LDMP is designed to develop a long-term data record of water-quality information at fixed river and tributary locations. Each year, chemical sampling is conducted biweekly from May through September, with concurrent short-term studies of chemical, biological, ecological and geomorphologic components of the Lower Delaware River corridor. The summer 1999 bacterial survey was one such short-term study, to be revisited as necessary to assess changes in the river's quality.

Study Area

The Delaware River, from the confluence of its east and west branches at Hancock, New York, flows 330 miles through the Appalachian Highlands, Valley and Ridge, Piedmont, Triassic Lowlands, and Coastal Plain geologic formations. The Delaware River basin drains 13,539 square miles. The non-tidal portion is about 200 miles long and drains about 6,780 square miles of the watershed above Trenton, NJ.

The Lower Delaware, or the reach extending from the Delaware Water Gap to Trenton, NJ, borders the states of New Jersey and Pennsylvania. New Jersey counties along this reach are Warren, Hunterdon, and Mercer. Pennsylvania counties are Monroe, Northampton, and Bucks. The Lower Delaware River's drainage area within the study reach is about 2,610 square miles from 51 named tributaries, along 75 miles of the main stem river. Major New Jersey tributaries, or those which comprise over 5% of the Lower Delaware River's drainage area within the reach, are the Paulins Kill, Pequest, and Musconetcong Rivers. Major Pennsylvania tributaries are the Lehigh River and Tohickon Creek. DRBC sampled these tributaries for bacteria, and established fixed long-term sampling sites near the mouth of each.

New Jersey and Pennsylvania classify many of their water resources along the study reach as being of high quality. New Jersey's high quality classifications relate to each stream's ability to support trout. Trout Production Waters are Buckhorn, Lopatcong, Merrill, and Pohatcong Creeks. Trout Maintenance Waters are Delawanna Creek, Hakiwokake Creek, and the Musconetcong, Paulins Kill, and Pequest Rivers. Pennsylvania designates high quality streams according to water-quality or other recreational or ecological features. High Quality Waters of the Lower Delaware are Aquetong, Cuttalousa, and Paunacussing Creeks, Fry's Run, and Rapp and Beaver Creeks, which are headwaters of Tinicum Creek. Exceptional Value Waters are a section of Bushkill Creek through Forks Township in Northampton County, and Cooks, Tinicum, and Tohickon Creeks in Bucks County. These waterways receive special protection status from their states, and were thus included in this study. They also are represented in DRBC's fixed network of monitoring stations.

Many smaller creeks were included in this study because they seldom receive attention from the state agencies, yet might provide valuable insights to cause and effect relationships concerning water-quality. In smaller watersheds, causes of water-quality problems tend to stand out clearly. Pollution sources are fewer and easily isolated. In the case of bacterial pollution, where sources are varied and diffuse, the greatest chance of quick success at protective or preventative efforts may be realized within these small watersheds.

The Lower Delaware River is heavily used for recreation. Canoe and tube liveries, and numerous public access areas, provide opportunities for swimming, fishing, and boating. This intense recreational use of the river led to establishment of sampling sites at or near all public access areas and bridges. Sampling these locations provided a good picture of water-quality, related to areas used for recreation in this reach of the river.

Some tributaries flow into either the Delaware & Raritan Canal in New Jersey or the Delaware Canal in Pennsylvania. The Delaware Canal in Pennsylvania parallels the Delaware River from Easton to Bristol. The Delaware & Raritan Canal in New Jersey parallels the Delaware River from Bull's Island, where water is diverted from the Delaware River to northern New Jersey. The canal is operated by the New Jersey Water Supply Authority as a major source of water for the central part of the state.

Background: Fecal Coliform and Enterococcus Bacteria

Fecal Coliforms & Enterococci: Indicators of Fecal Pollution and Pathogens

The Delaware River Basin Commission uses a fecal coliform stream quality objective in Zones 1D and 1E as indicative of bacterial water-quality. Fecal coliforms were, for many years, preferred as the indicator group for recreational water-quality. This common standard (threshold of 200 colonies per 100 ml) was based upon studies conducted in the 1940's and 1950's, but the U.S. EPA (1986) later recognized deficiencies. Studies showed that enterococcus density was more strongly indicative of swimming-related gastroenteritis, where fecal coliform density showed little relationship to this and other swimming-related illnesses (U.S. EPA, 1986). U.S. EPA has recommended use of *E. coli* or enterococci as preferential indicators of fecal pollution for primary-contact recreation, in place of fecal coliforms. For this reason, DRBC chose to study both fecal coliforms, for which a standard exists, as well as enterococci, which are suggested to be more strongly associated with human health effects.

Fecal coliforms are part of the total coliform group, which includes the genera *Escherichia*, *Citrobacter*, *Enterobacter*, and *Klebsiella*. The predominant fecal coliform is *Escherichia coli*, which constitutes a large portion of the bacterial population of the human intestine. *E. coli* is a species indicative of fecal pollution and the possible presence of enteric pathogens. Fecal coliform bacteria are distinguished from total coliforms by their ability to grow at higher temperatures (Csuros and Csuros, 1999). For this study, fecal coliform density was measured using the membrane filter procedure 9222D, with m-FC media (Standard Methods for the Examination of Water and Wastewater, 20th edition, 1998).

The enterococcus group is a sub-group of the fecal streptococci. The enterococcus group is composed of *Streptococcus faecalis*, *S. faecium*, *S. gallinarum*, and *S. avium*. The occurrence of fecal streptococci in water indicates contamination originating from warm-blooded animals.

The enterococcus portion of the fecal streptococcus group is a valuable bacterial indicator of the extent of contamination of recreational surface waters. Enterococci are the most efficient bacterial indicators of water-quality associated with bathing (Dufour, 1984). The membrane filter procedure for enumerating enterococci detects mainly *S. faecalis* and *S. faecium*, found in the intestinal tracts of humans and such animals as cats, dogs, cows, horses, and sheep. The federal guideline for recreational freshwaters is 33/100 ml (U.S. EPA, 1986). For this study, enterococci densities were measured using the membrane filter procedure 9230C, with mE agar (Standard Methods 20th Edition, 1998; U.S. EPA, 1985; 1997). The U.S. EPA Region II laboratory in Edison, NJ, conducted these tests for DRBC.

Fecal coliforms and enterococci are easily detected and quantified, and indicate animal and human fecal pollution. They also represent potential presence of other enteric pathogens that are less-easily detected in a cost-efficient manner, and which were not examined in this survey. These waterborne pathogens enter a human host through intact or broken skin, inhalation, ingestion, aspiration, or through mucous membranes of the eye, ear, nose, mouth, or genitals. Surface water pathogens include *Salmonella*, *Shigella*, enteroviruses, protozoans such as *Cryptosporidium*, *Giardia*, and other multi-cellular parasites. If sufficient nutrients exist, other pathogens may opportunistically multiply, such as *Pseudomonas aeruginosa*, *Klebsiella*, *Vibrio*, and *Aeromonas hydrophila*. Another pathogen, associated with the skin, mouth, and nose of bathers, is *Staphylococcus aureus*. Useful references to these organisms and associated diseases include Dufour (1984), Olivieri et al. (1977), and Krieg (1984), as well as Standard Methods for the Examination of Water and Wastewater, 20th Ed. (1998).

The Centers for Disease Control and Prevention, USEPA, and the Council of State and Territorial Epidemiologists maintain a national surveillance program on waterborne diseases originating from drinking and recreational waters (Kramer et al., 1996a). Summary data from 1985-1994 (Kramer et al., 1996b) listed 21 outbreaks originating from outdoor recreational waters, though only one outbreak originated from stream water, and 20 came from lakes or ponds. Agents of disease included *Shigella*, *Pseudomonas*, *Legionella*, *Leptospira*, and *E. coli*. No outbreaks are known to have occurred from recreation in waters of the Delaware River Basin.

Watershed Sources and Pathways of Bacteria Contamination

Sources of bacteria in a watershed are difficult to track. The Center for Watershed Protection (1999), in its special issue bulletin on bacteria, reviewed existing knowledge concerning sources and pathways of bacteria within a watershed. Watershed sources include sewer lines, septic systems, livestock, wildlife, waterfowl, pets, soils, and plants. According to the U.S. Geological Survey (Smith et al., 1992), about 20% of all water-quality samples exceed the 200/100ml fecal coliform standard. Among those 20% of samples, highest fecal coliform densities were collected from agricultural and urban watersheds. Lowest densities were found in forested and pastured watersheds. There are such a wide variety of sources, however, that variability among samples is very high. This means that comparison of watersheds to one another can be very difficult. Each watershed is unique in its blend of bacteria sources. Some predictors of bacteria levels include population density, age of development, and percent of residential development (Glennie, 1984). Factors such as rainfall amount and intensity, time between rain events and sampling, turbidity, and suspended solids are commonly correlated with bacteria levels.

Coliform bacteria may be human or animal in origin. If human, the coliforms come mainly from sewage. Though waste treatment has improved greatly in the past 30 years, some plants are overloaded or inefficiently operated, producing high bacteria levels in streams. Other sources include: combined sewer overflows (CSO's); sanitary sewer overflows; illegal sanitary connections to storm drains; dumping of waste into storm drains and streams by septage trucks, RV's, or portable toilets; and failing septic systems.

Non-human sources of bacterial pollution may be associated with humans. The list of "wildlife" that are common sources in an urban or urbanizing watershed include animals associated with humans, such as dogs, cats, rats, raccoons, pigeons, gulls, ducks, and geese. Livestock and rural wildlife contribute as well and include cattle, horses, poultry, beaver, muskrats, deer, and waterfowl. Non-human contribution of bacteria to a watershed may be very significant. A study using human RNA coliphages (Alderiso et al., 1996) found that 95% of fecal coliforms in urban storm water were non-human in origin. Samadpour and Checkowicz (1998) conducted microbial tracking in a lightly developed Washington watershed, and found that the primary sources of fecal coliforms were dogs and livestock, especially in areas with horse farms and small ranches. They found that vulnerability to fecal coliform contamination increased in areas where livestock density was high, and where scant attention was paid to grazing and riparian management practices.

In addition to direct human and non-human sources of bacteria contamination, the drainage system itself provides a sink for bacteria sources. Burton et al. (1987) found that bacteria persist in bottom sediments for weeks or months, especially in warm, dark, moist and organic-rich conditions. Van Donsel and Geldreich (1971) found that sediment bacteria are found in densities 3-4 orders of magnitude higher than in the surrounding water column. Optimal bacteria growth conditions may be found in ponds, lakes, catchments, ditches, drains, roadway curbs, leaf piles, grass swales, and moist soils (Center for Watershed Protection 1999). Bannerman et al. (1993) and Steuer et al. (1997) found that residential lawns, driveways, and streets are major source areas for bacteria.

Regulatory Context

DRBC Guidelines and Standards

The study area covers most of Zone 1D and all of Zone 1E of the Delaware River, an interstate non-tidal river. The Delaware River Basin Commission Administrative Manual - Part III: Water Quality Regulations (DRBC 1996) contains stream quality objectives for Zones 1D and 1E, including fecal coliform bacteria. The standard states that fecal coliforms should not exceed 200 per 100 milliliters as a geometric average; samples shall be taken at such frequency and location as to permit valid interpretation.

No DRBC enterococcus criteria exist for the non-tidal Delaware River, though the U.S. EPA urges adoption of enterococci and *E. coli* as primary contact indicators of choice. Below the head of tide, DRBC set enterococcus standards by Resolution No. 91-6 in 1991, ranging from 33/100ml to 88/100ml, based upon attainable uses in Zones 2 through 5 of the Delaware Estuary. DRBC also retained fecal coliform standards for these Zones of the estuary, ranging according to location from 200 to 770/100ml. This study contributes data toward establishment of enterococcus standards for the non-tidal Delaware River.

Federal Guidelines and Criteria

The U.S. EPA freshwater enterococci criterion for bathing (full body contact) recreational waters is 33/100ml geometric mean. This criterion is based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period) with a 0.4 log standard deviation. Fecal coliform criteria remain at the historic 200/100ml geometric mean density. The U.S. EPA's Action Plan for Beaches and Recreational Waters (1999) states that "EPA will develop policies to ensure that states and tribes adopt the currently recommended Ambient Water Quality for Bacteria – 1986 and make the transition to monitoring for *E. coli* and enterococci indicators rather than total coliforms or fecal coliforms."

With three or less samples taken over the summer months at any given site, this study did not meet the statistical requirements for application of the U.S. EPA criteria. The summer 1999 sampling effort was sufficient, however, to begin describing water-quality conditions and to identify potential problem spots along the Delaware River corridor. Graphical presentations of results display criteria guidelines, though it should be recognized that sampling was not conducted with the necessary frequency to assess compliance with federal enterococcus criteria.

State Guidelines and Standards

Pennsylvania and New Jersey bacteria guidelines and standards are provided here for comparison with those of DRBC and U.S. EPA. A review of state guidelines is included in EPA's Bacterial Water Quality Standards Status Report (USEPA 1998). New Jersey uses the fecal coliform criterion of 200/100ml and an enterococcus criterion of 33/100ml for the state's freshwater. At present, only New Jersey's enterococcus criterion is applicable to the non-tidal Delaware River. Pennsylvania's Chapter 93 Water Quality Standards apply the fecal coliform standard of 200/100ml to meet the Water Contact use classification for the swimming season, and 2000/100 ml the rest of the year. The exception includes the Delaware River, where the 200/100 ml fecal coliform stream quality objective applies year-round.

Methods

Delaware River and tributary sampling sites are listed by river-mile in Table 1. For the Lower Delaware, all named tributaries are listed, even those which do not receive regular attention from monitoring agencies. This is a "check list" of tributaries used for study planning purposes, and shows all named tributaries between each Delaware River monitoring station.

Data were collected by DRBC according to methods established under DRBC's quality assurance project plan (DRBC, 1999a). The U.S. EPA Region II laboratory in Edison, NJ, provided microbiological analyses using the membrane filtration procedures described in Standard Methods for the Examination of Water and Wastewater, 20th Edition (1998). Routine water-quality parameters collected included dissolved oxygen (DO), air temperature, water temperature, DO percent saturation, conductivity, pH, and gage height (tributaries only). Two types of sampling runs were required to meet logistical requirements of establishing a fixed water-quality network and meeting holding times for bacteria and nutrient sampling. At bacteria survey (BA) sites, fecal coliform and enterococci samples were collected with routine water chemistry parameters. At fixed water-quality (WQ) sites, sampling included nutrients

(Nitrate+Nitrite Nitrogen, Ammonia+Ammonium Nitrogen, Orthophosphate, and Chlorophyll A) and routine parameters.

June through August 1999 daily precipitation data from National Weather Service climate stations in Allentown, PA (Lehigh Valley International Airport, station ABE), Belvidere Bridge, NJ (station BELN4), and Lambertville, NJ (station LBVN4) were downloaded from the National Climate Data Center web site. Stream flow records from U.S. Geological Survey gages along the Delaware River (Montague, Belvidere, Riegelsville, and Trenton) were also obtained for the study period. Sites were located on DRBC recreation maps for the Delaware River, and on USGS 7.5 minute topographic maps.

TABLE 1. Delaware River & Tributary Sampling Sites 1999

WQ sites: Basic chemistry, nutrients, bacteria; long-term sampling sites

BA sites: Special study only, incl. basic chemistry, fecal coliform and enterococcus (Jun, Jul, Aug 1999)

NO sites - Were not sampled in 1999, but listed here for reference and future study planning purposes.

n=# is number of bacteria samples collected summer 1999

DRY = All visits dry.

Name	Drainage		Sample 1999, n=#
	River Mile	Area (sq. mi.)	
Lower Delaware stations			
Assunpink Creek, Trenton, NJ (future site)	133.80	91.40	NO
Delaware River @ Calhoun Street Bridge, NJ-PA	134.34	6780.00	WQ, n=6
Gold Run @ Trenton CC bridge, Trenton, NJ	137.25	1.66	NO
Buck Creek above Main St Bridge, Yardley, PA	138.00	6.99	WQ, n=3
Delaware River @ Yardley PAFBC Access, PA	138.80	6771.00	BA, n=3
Delaware River @ Scudders Falls Access, NJ	139.20	6770.00	BA, n=3
Dyers Creek @ Rt. 32 Bridge, PA	139.80	1.20	BA, n=3
Jacobs Creek above Rt. 29 Bridge, NJ	140.46	13.30	WQ, n=3
Houghs Creek @ Aqueduct & Taylorsville Rd, PA (dry most of study)	140.60	5.19	BA, n=1
Delaware River @ Washington Crossing Bridge, NJ-PA	141.80	6750.00	WQ, n=6
Fiddlers Creek @ Private Bridge off Fiddlers Creek Rd, NJ	143.20	2.02	BA, n=2
Jericho Creek @ Stony Brook Rd Bridge, PA (dry much of study)	144.20	9.63	BA, n=2
Moore Creek @ Iron Bridge Farm, NJ	145.20	10.20	BA, n=3
Pidcock Creek @ Bowmans Hill Wildflower Preserve Bridge, PA	146.30	12.70	BA, n=3
Dark Hollow Run, PA	148.20	0.71	DRY
Aquetong Creek @ Mechanic St Bridge, New Hope, PA	148.50	8.01	WQ, n=3
Delaware River @ Lambertville Boat Launch, NJ	148.55	6685.00	BA, n=3
Swan Creek @ Union St Bridge, Lambertville, NJ	148.60	3.28	BA, n=3
Delaware River @ Lambertville-New Hope Bridge, NJ-PA	148.70	6680.00	BA, n=6
Rabbit Run, PA	149.45	0.42	DRY
Alexauken Creek @ Rt. 29 Bridge, Lambertville, NJ	149.50	15.00	BA, n=3
Primrose Creek @ Rt. 32 Bridge, PA	150.50	est. 3.00	BA, n=3
Delaware River @ Stockton Bridge, NJ-PA	151.90	6660.00	WQ, n=6
Wickecheoke Creek @ Rt. 32 Bridge, NJ	152.51	26.60	WQ, n=3
Lokatong Creek @ Rosemont-Raven Rock Rd Bridge, NJ	154.00	23.20	WQ, n=3
Cuttalossa Creek @ Cuttalossa Rd, PA	154.50	est. 3.00	BA, n=3
Delaware River @ Lumberville-Raven Rock Foot Bridge, NJ-PA	155.40	6598.00	WQ, n=6
Paunacussing Creek @ Rt. 32 Bridge, PA	155.60	7.87	WQ, n=3
Delaware River @ Delaware & Raritan Canal Diversion (USGS site)	156.20	6588.00	NO
Hickory Creek, PA	156.98	1.50	DRY

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BA sites: Special study only, incl. basic chemistry, fecal coliform and enterococcus (Jun, Jul, Aug 1999)

NO sites - Were not sampled in 1999, but listed here for reference and future study planning purposes.

n=# is number of bacteria samples collected summer 1999

DRY = All visits dry.

Name	Drainage		Sample 1999, n=#
	River Mile	Area (sq. mi.)	
Lower Delaware stations			
Tohickon Creek @ Rt. 32 Bridge, PA	157.00	112.00	WQ, n=3
Delaware River @ Point Pleasant Diversion (future site)	157.20	6472.00	NO
Cain's Run (AKA Warsaw Creek) @ Rt. 29 Bridge, NJ	159.50	1.60 (est.)	BA, n=1
Smithtown Creek, PA	159.90	est. 1.00	DRY
Warford Creek @ Rt. 29 Bridge, NJ	160.50	1.60 (est.)	BA, n=1
Tinicum Creek @ Tinicum Creek Rd above Rt. 32 Bridge, PA	161.60	24.00	WQ, n=3
Copper Creek @ Rt. 29 Bridge, NJ	162.90	3.27	DRY
Delaware River @ Kingwood Access, NJ	163.10	6440.00	BA, n=3
Little Nishisakawick Creek @ Rt. 29 Bridge, Frenchtown, NJ	164.00	3.51	BA, n=1
Nishisakawick Creek @ Kingwood Ave/Rt. 12 Bridge, Frenchtown, NJ	164.10	11.10	WQ, n=3
Delaware River @ Frenchtown-Uhlerstown Bridge, NJ-PA	164.30	6430.00	WQ, n=6
Harihokake Creek @ Rt. 29 Bridge near Milford, NJ	165.70	9.85	BA, n=2
Hakihokake Creek @ Bridge St Bridge, Milford, NJ	167.20	17.50	WQ, n=3
Delaware River @ Milford-Upper Black Eddy Bridge, NJ-PA	167.70	6380.00	WQ, n=6
Gallows Run @ Rt. 611/32 Jct. Bridge, PA	171.80	8.72	BA, n=3
Cooks Creek @ Red Bridge Rd Bridge, PA	173.70	29.50	WQ, n=3
Delaware River @ PAFBC Riegelsville Access, PA	173.90	6331.00	BA, n=3
Musconetcong River @ River Rd/Rt. 627 Bridge, Riegelsville, NJ	174.60	156.00	WQ, n=3
Delaware River @ Riegelsville Bridge, NJ-PA	174.80	6175.00	WQ, n=6
Frys Run (AKA Frya Run) @ Northampton Co. Park Bridge abv Rt. 611, PA	176.60	6.14	WQ, n=3
Pohatcong Creek @ River Rd Bridge, NJ	177.36	57.10	WQ, n=3
Delaware River @ Wy-Hit-Tuk Access off Rt. 611, PA	181.00	6112.00	BA, n=3
Lopatcong Creek @ Main St Bridge, Phillipsburg, NJ	182.00	14.70	WQ, n=3
Lehigh River @ Rt. 611 Bridge, Easton, PA	183.66	1361.00	WQ, n=3
Delaware River @ Easton Northampton Street Bridge, NJ-PA	183.82	4717.00	WQ, n=6
Bushkill Creek @ Rt. 611 Bridge, Easton, PA	184.10	80.00	WQ, n=3
Delaware River @ Eddyside Park Access (private), PA	185.00	4630.00	BA, n=3
Mud Run @ Rt. 611 Bridge, PA	189.10	6.00	DRY
Delaware River @ Sandt's Eddy Access, PA	189.20	4620.00	BA, n=3
Martins Creek @ Little Creek Rd Bridge off Rt. 611, PA	190.65	44.50	WQ, n=3
Buckhorn Creek @ Hutchinson Rd Bridge off Rt. 519, NJ	192.90	11.80	WQ, n=3
Oughoughton Creek @ Depues Rd Bridge, PA	194.32	11.90	DRY
Delaware River @ PP&L Martins Creek Access, PA	194.40	4540.00	BA, n=3
Pophandusing Brook @ Spring St Bridge, Belvidere, NJ	197.66	5.62	BA, n=3
Pequest River @ Orchard St Bridge, Belvidere, NJ	197.80	157.00	WQ, n=3
Delaware River @ Belvidere-Riverton Bridge, NJ-PA	197.84	4377.00	WQ, n=6
Allegheny Creek @ River Rd Bridge, PA	199.76	9.06	BA, n=3
Delaware River @ Driftstone Campground Access (private), PA	203.00	4365.00	BA, n=3
Delawanna Creek @ Rt. 46 Bridge, NJ	205.20	4.49	WQ, n=3
Paulins Kill @ Rt. 46 Bridge near Rt. 94 Ramp, NJ	207.16	177.00	WQ, n=3
Jacoby Creek @ Rt. 611 Bridge, Portland, PA	207.48	6.45	BA, n=3
Delaware River @ Columbia-Portland Foot Bridge, NJ-PA	207.50	4177.0	WQ, n=6

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NO sites - Were not sampled in 1999, but listed here for reference and future study planning purposes.

n=# is number of bacteria samples collected summer 1999

DRY = All visits dry.

Name	Drainage		
	River Mile	Area (sq. mi.)	Sample 1999, n=#
Lower Delaware stations			
Stony Brook @ access road culvert above I-80, NJ	208.76	est. 2.0	DRY
Slateford Creek @ National Park Rd Bridge, DWGNRA, PA	209.58	2.95	BA, n=3
Dunnfield Creek @ Appalachian Trail Footbridge off I-80, NJ	211.48	3.56	WQ, n=3

A field manual was created to document sampling logistics and facilitate study replication. See Appendix A for applicable portions of the 1999 Lower Delaware Cooperative Monitoring Program Field Instruction Manual (DRBC 1999c). The manual includes checklists, dates, staffing, sites visited, driving directions, and collection and transport procedures for two types of sampling runs. WQ runs pertain to collection procedures for fixed sites, without collection of bacteria samples, but including nutrient samples. BAC runs pertain to bacterial sampling trips, where holding times are critical to data quality, and transport to Edison, NJ (USEPA Region II laboratory) dictated the number of sites visited per day. Listed in Appendix B are descriptions of Lower Delaware sampling sites, with locations of DRBC flow gage marks.

Table 2 lists water-quality parameters and methods used for the Lower Delaware Monitoring Program. Reach-wide characterizations were conducted for dissolved oxygen, dissolved oxygen percent saturation, temperature, pH, conductivity, fecal coliforms, and enterococci (n=3 to 8, depending upon site). Insufficient data were collected for nutrients (nitrate + nitrite nitrogen, phosphate phosphorus, chlorophyll a, pheophytin a) to conduct reach-wide characterization (n=1). Nutrient data were included in Appendix C, but are not discussed here.

TABLE 2: Lower Delaware Monitoring Program Water Chemistry and Bacterial Parameters.

Parameter	Standard Methods¹ – Number	Equipment	Min – Max	Accuracy (±)
Flow	See Appendix B for locations	Pygmy meter	0.07-3.00 fps	5%
Air temperature	2550 – thermometric	Thermometer	-10-110 °C	1 °C
Water temperature	2550 – thermometric	Thermometer	-10-110 °C	1 °C
		Thermistor probe (DO meter)	-5-45 °C	0.7 °C
		Thermistor probe (conductivity meter)	-2-50 °C	0.6 °C
Dissolved oxygen	4500-O C. - azide modification of Winkler titration method	Kit	0-20 mg/l	20-60 µg/l
	4500-O G. – membrane electrode	YSI Meter	0-20 mg/l	0.2 mg/l
Specific conductance	2510 - platinum electrode conductivity cell	YSI Meter	0-19,999 µmhos /cm	2 µmhos/cm
PH	4500-H+	pH Testr 2 meter	4-10 units	0.25 units
Nitrate+Nitrite Nitrogen	Palintest Method – Zinc Reduction, Photometer 570 nm	YSI 9100 photometer	0-1 mg/l N 0-20 mg/l N	.02 mg/l .2 mg/l
Ammonia	4500-NH3 F. Phenate Method	YSI 9100 photometer	0.01-1.00 mg/l	0.05 mg/l
Ortho-phosphate	4500-P E. Ascorbic acid reduction	YSI 9100 photometer	0.01-3.00 mg/l	0.01 mg/l
Chlorophyll a, Pheophytin a	10200-Spectrophotometric (DMSO extraction), by NJDEP Bureau of Marine Water Monitoring	NJDEP Spectrophotometer	> 0.42 ppb	1 ppb
Enterococcus (EPA Region 2 Lab)	9230 C. mE agar for enterococci	Membrane filtration	> 0 colonies/100 ml	NA
Fecal coliform (EPA Region 2 Lab)	9222 D. m-FC media	Membrane filtration	> 0 colonies/100 ml	NA

¹ Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

Results and Discussion

Refer to the appendices for monitoring data (Appendix C), bacteria summaries (Appendix D) and daily precipitation at selected stations (Appendix E). In the results sections, graphical presentations include trend lines, though it should be noted that sampling frequency was insufficient to derive strong statistical relationships. As data collection continues over future years, statistical power of the data set should improve, revealing spatial and temporal trends. All graphs present water-quality and bacteria data organized by Delaware River mile. Delaware River mile locations of tributaries are at the confluence of the tributary to the Delaware River.

Delaware River Flow and Rainfall, Drought of Summer 1999

As the study period began in June 1999, the Delaware River Basin above Trenton was experiencing a rainfall deficit of 6.23 inches since August 1998 (Figure 2). From June through August 1999, rainfall above Trenton averaged 7.16 inches, a deficit of 4.82 inches from the normal rainfall of 11.98 inches. By the end of August 1999, the precipitation deficit reached 11.05 inches since the previous August, prompting drought emergency actions by DRBC and the states of New Jersey and Pennsylvania. The study therefore represents water-quality conditions during a drought, with severe drought conditions in some watersheds.

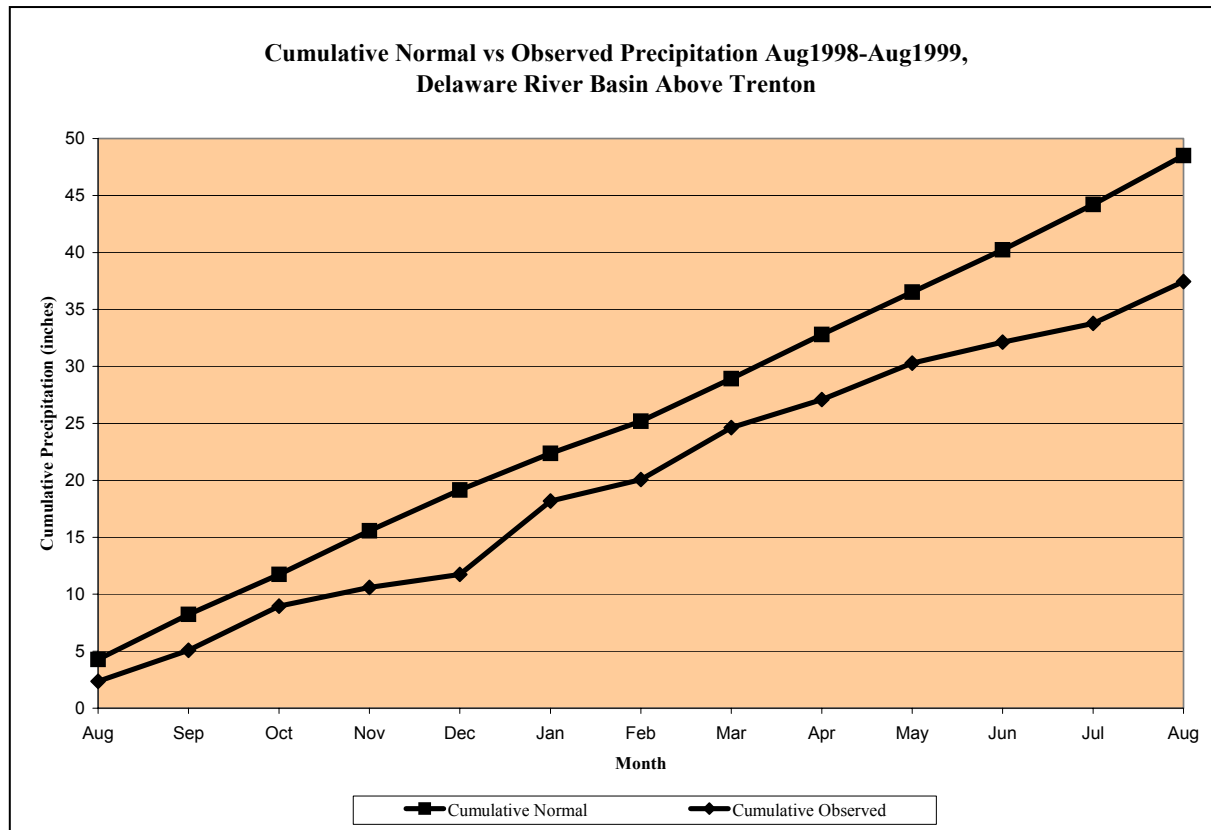


Figure 2.
Cumulative normal versus observed precipitation for the study period.

Drought circumstances created optimal dry-weather bacteria sampling conditions, and all sampling events save the last were conducted under conditions unaffected by heavy antecedent rainfall. During the study period, up to 66% of the flow of the Delaware River at Trenton originated from upper-basin reservoir releases, and many tributaries were completely dry. Pennsylvania tributaries found dry during all or part of the study period included Houghs, Jericho, Dark Hollow Run, Rabbit Run, Hickory, Smittstown, Tinicum, Mud Run, and Oughoughton Creeks. New Jersey tributaries found dry included Jacobs, Fiddler, Lockatong, Warsaw, Warford, Copper, Little Nishisakawick, Nishisakawick, Harihokake, Stony Brook, and Dunnfield Creeks. Dry creeks were either missed completely or insufficiently sampled for calculation of averages. Figure 3 shows June through August 1999 daily average flow of the Delaware River at Trenton, NJ. Rain and sampling events are marked along the study timeline.

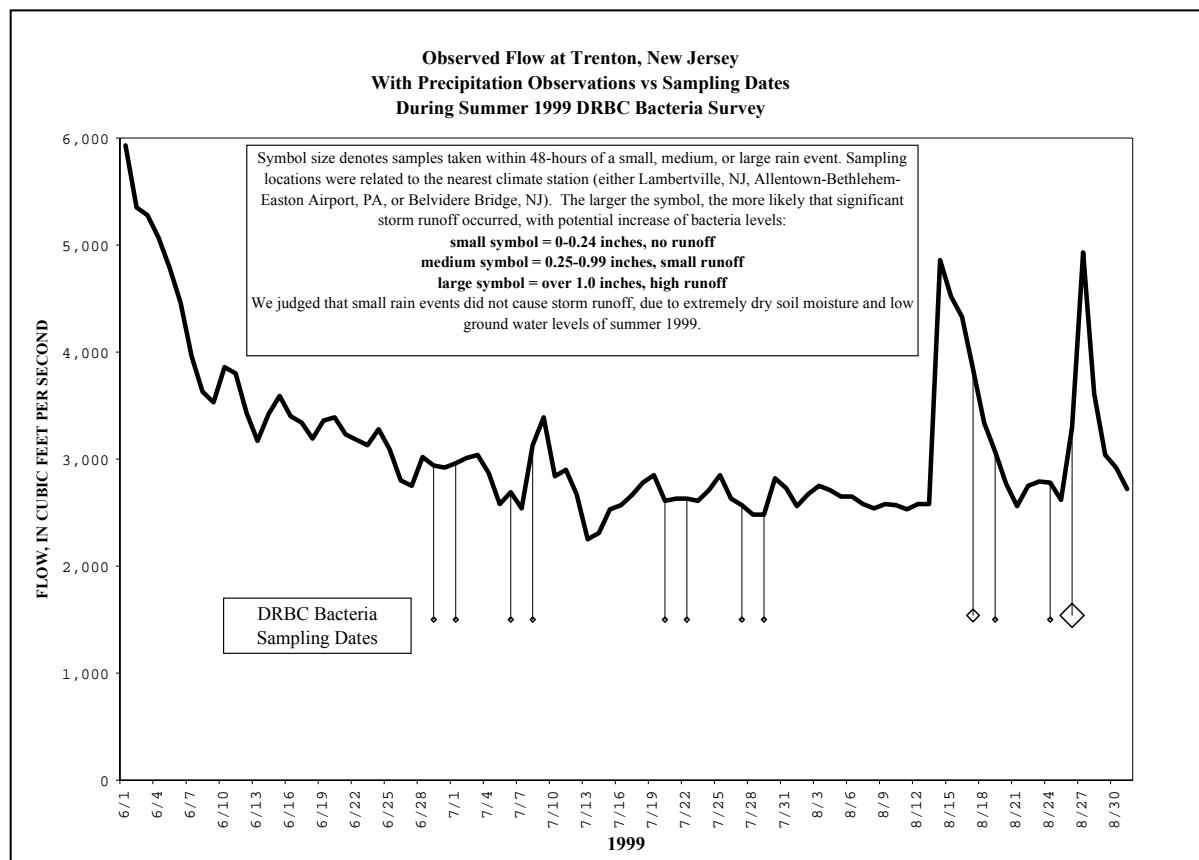


Figure 3.

Observed Flow at Trenton, NJ, with precipitation related to sampling dates during the 1999 DRBC Bacteria Survey. Only the last sampling event was conducted within 48 hours of a large rain event, though inclusion of this data did not significantly change average bacteria densities.

Water Quality – Main Stem Delaware River

To facilitate water-quality trend analysis and comparison along the non-tidal Delaware River from the confluence of the East and West Branches at Hancock, NY, to Trenton, NJ, the DRBC/National Park Service Scenic Rivers Monitoring Program (SRMP) provided water-quality data for the study period. National Park Service personnel collect water-quality data under DRBC/NPS quality assurance protocols (DRBC, 1999b), sampling the Delaware River from Hancock, NY, to the Delaware Water Gap. SRMP data are included in all figures that display results above river-mile 210.

Delaware River water-quality generally met standards and criteria throughout the non-tidal Delaware River. Though average dissolved oxygen values (Figure 4) declined somewhat from Hancock (River-Mile 332) to Trenton (River-Mile 134), trending downward from around 8.5 to 7.9 mg/l, the dissolved oxygen saturation trend remained steady near 101% (Figure 5). Since the river warms as it flows from the Delaware Water Gap to Trenton (Figure 6), its oxygen-holding capacity declines. Some areas of the river reached super-saturated conditions, commonly attributed to heavy aquatic plant growth, which was observed at many river stations through the summer months.

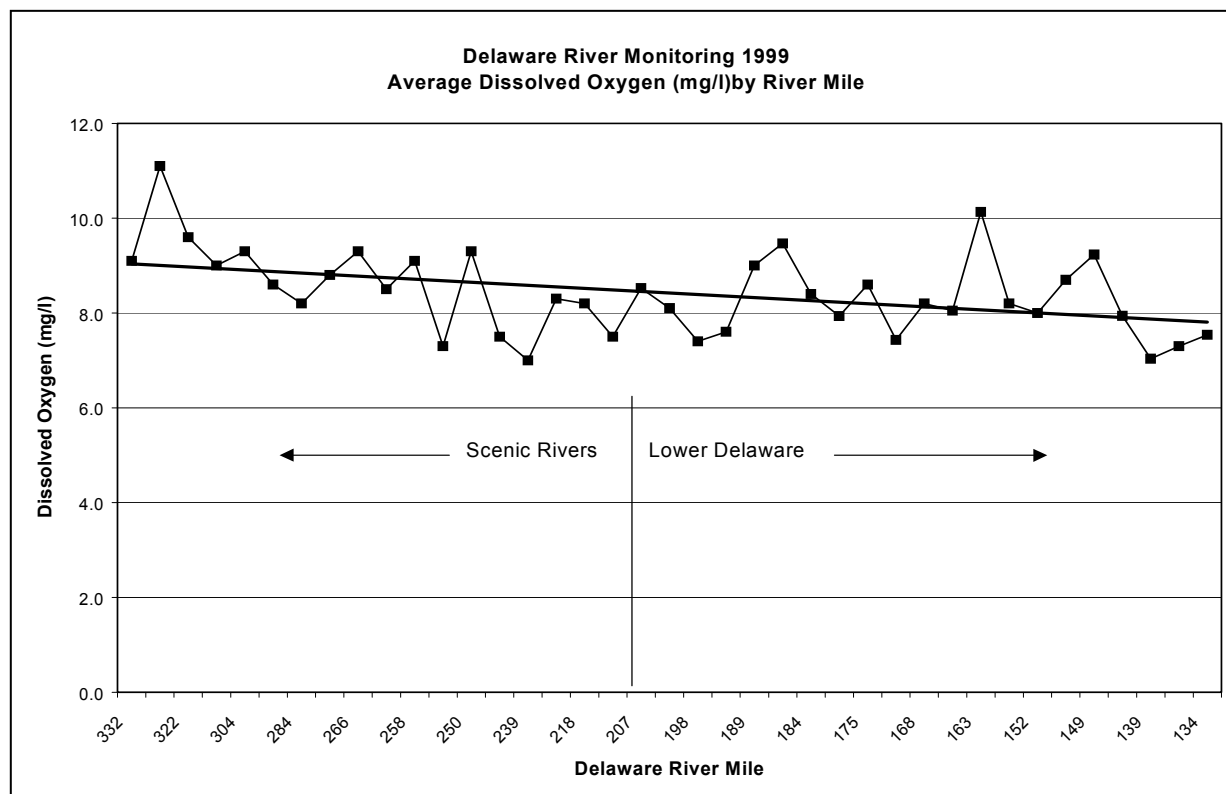


Figure 4.

Delaware River average dissolved oxygen concentration (mg/l), Hancock, NY to Trenton, NJ (n=3 to 6, dependent upon site). Trends show that concentration declines downstream, though saturation remains steady (See Figure 5).

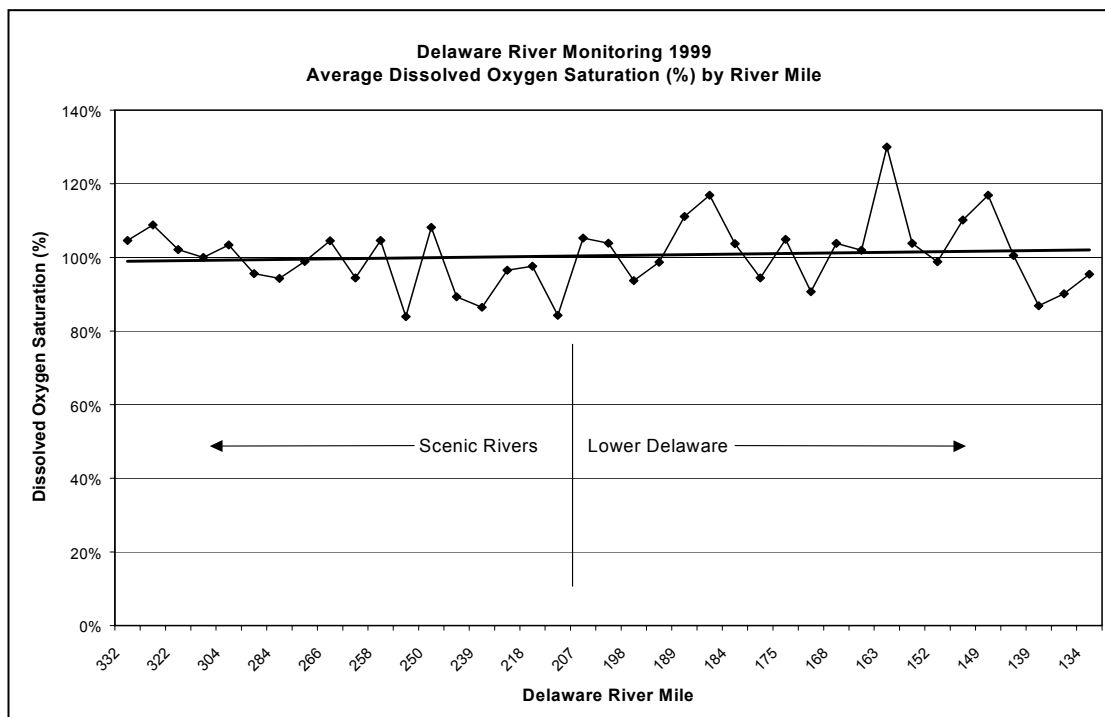


Figure 5.

Delaware River Dissolved Oxygen Saturation (%), Hancock, NY, to Trenton, NJ. The upstream-downstream saturation trend line remained steady around 101% (n=3 to 6, depending on site), due to declining oxygen-holding capacity with rising temperature (see Figure 6).

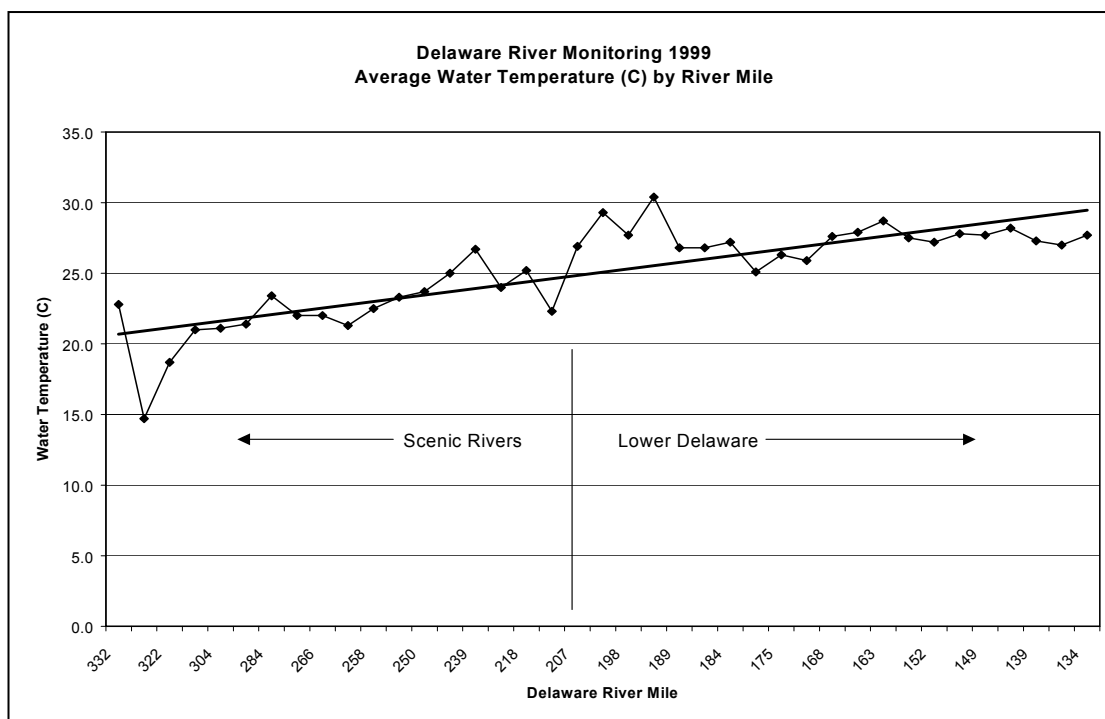


Figure 6.

Delaware River average water temperature (°C) from Hancock, NY, to Trenton, NJ. Average water temperature trended upward from upstream to downstream (n=3 to 6, dependent upon site). The low point to the left of the graph (14.9 °C, n=3) was taken from the West Branch Delaware River, which is affected by bottom-releases from Cannonsville Reservoir. The highest average temperature at river-mile 194 (30.4°C, n=3) was taken just downstream from the PP&L Martins Creek power plant's waste stream.

Figure 7 displays average pH during the summer months along the Delaware River. DRBC's pH standard for Zones 1D and 1E specifies that values should fall between 6.0 and 8.5. The lower limit was never crossed during this study, but the upper limit was exceeded in two areas of the Delaware River. High pH average values were observed at Lambertville Boat Access (avg. pH 8.6, n=3) on the New Jersey side of the river, and along a reach above Easton, PA, at Sandt's Eddy Fishing Access (avg. pH 8.6, n=3). In July and August, pH values exceeded 8.5 from Martins Creek Access to Sandt's Eddy to Eddyside Park. pH values are typically high during the day, due to photosynthesis by submerged aquatic vegetation, periphyton, and phytoplankton. This may be a natural condition, subsiding with increased flows and plant senescence in fall. However, the presence of high nutrient concentrations may trigger an increase in aquatic plant growth, leading to the unusually high pH values observed. Further study may reveal whether the high pH values observed in 1999 result from natural conditions, or from nutrient enrichment. If natural conditions cause pH values to exceed standards, perhaps the upper limit of the pH standard should be re-examined. In the case of pH, DRBC Stream Quality Objectives are inconsistent with State pH standards, which designate an upper limit of pH 9.0.

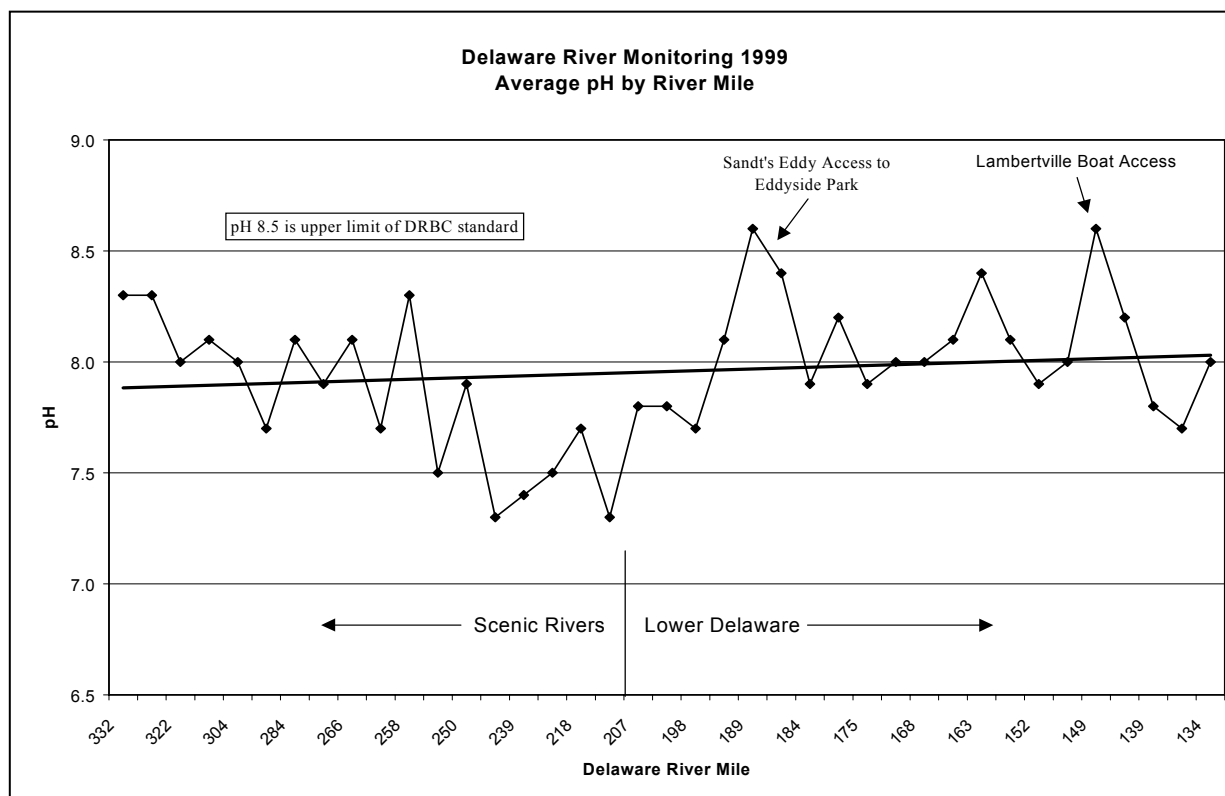


Figure 7.

Average pH along the Delaware River from Hancock, NY, to Trenton, NJ (n=3 to 8, depending on site). The upper limit of pH 8.5 was exceeded at the two labeled areas.

Conductivity measures the ability of an aqueous solution to carry an electric current, which depends on the presence and concentration of inorganic ions in the stream, and is also a function of temperature. In Figure 8, conductivity (in $\mu\text{mhos/cm}$) increases as the river flows from Hancock to Trenton. The pattern shows that as tributaries contribute flow, human and industrial activities cumulatively contribute waste products. An average conductivity spike of 296 $\mu\text{mhos/cm}$ (n=3) is shown at the Martins Creek Boat Access, where several possible upstream sources contribute ion loads. The PPL Martins Creek Generating Station discharge enters just upstream of the access sampling site. The power plant may or may not be a source of

the increase in conductivity observed. In this area, the Delaware River passes through a band of typically high-conductivity carbonate rock. Another possible contributor is the Pequest River, a major New Jersey tributary to the Delaware, where average conductivity measured 451 $\mu\text{mhos/cm}$ ($n=4$). Groundwater inflow also contributes ions, as wells in the near vicinity display conductivity values over 500 $\mu\text{mhos/cm}$ (Pers. Comm., DRBC Project Review Branch).

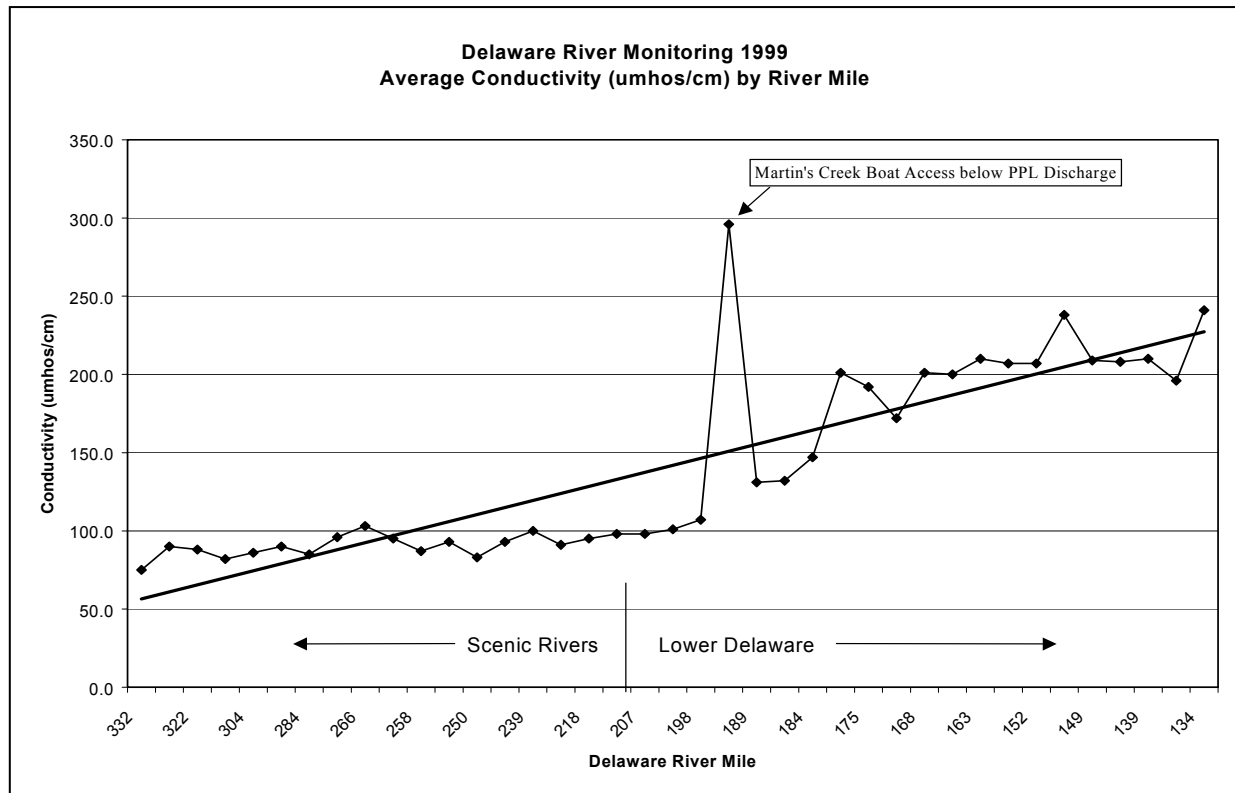


Figure 8.

Average conductivity ($\mu\text{mhos/cm}$) of the Delaware River between Hancock, NY, and Trenton, NJ ($n=3$ to 8, depending on site). Increasing drainage area, tributary inputs, and human activity account for the upward trend. Unusually high peak at Martin's Creek boating access merits further investigation of sources near the sampling site.

Fecal Coliform Bacteria - Mainstem Delaware River

The fecal coliform standard of 200/100ml was not exceeded in the main stem Delaware River. Although there were too few samples taken over the study period at any single location to determine compliance with water-quality standards, available data were compared to bacteria standards. There were relatively high ($>100/100\text{ ml}$) geometric means at 3 locations: Stockton Bridge (103/100ml, $n=6$), Lambertville Boat Access (188/100ml, $n=3$), and Scudders Falls Access (114/100ml, $n=3$). The Stockton Bridge mean value was affected by a single high fecal coliform sample. Bacteria sources are unknown in the vicinity of Stockton and Scudders Falls. A large population of waterfowl was observed at Lambertville, and may have some impact on fecal coliform values. Figure 9 displays Delaware River geometric mean fecal coliform densities during the summer 1999 survey, and shows an increasing trend toward higher fecal coliform counts from Hancock, NY, to Trenton, NJ. Appendix D summarizes geometric mean values at Delaware River stations, and Appendix C lists individual sample data.

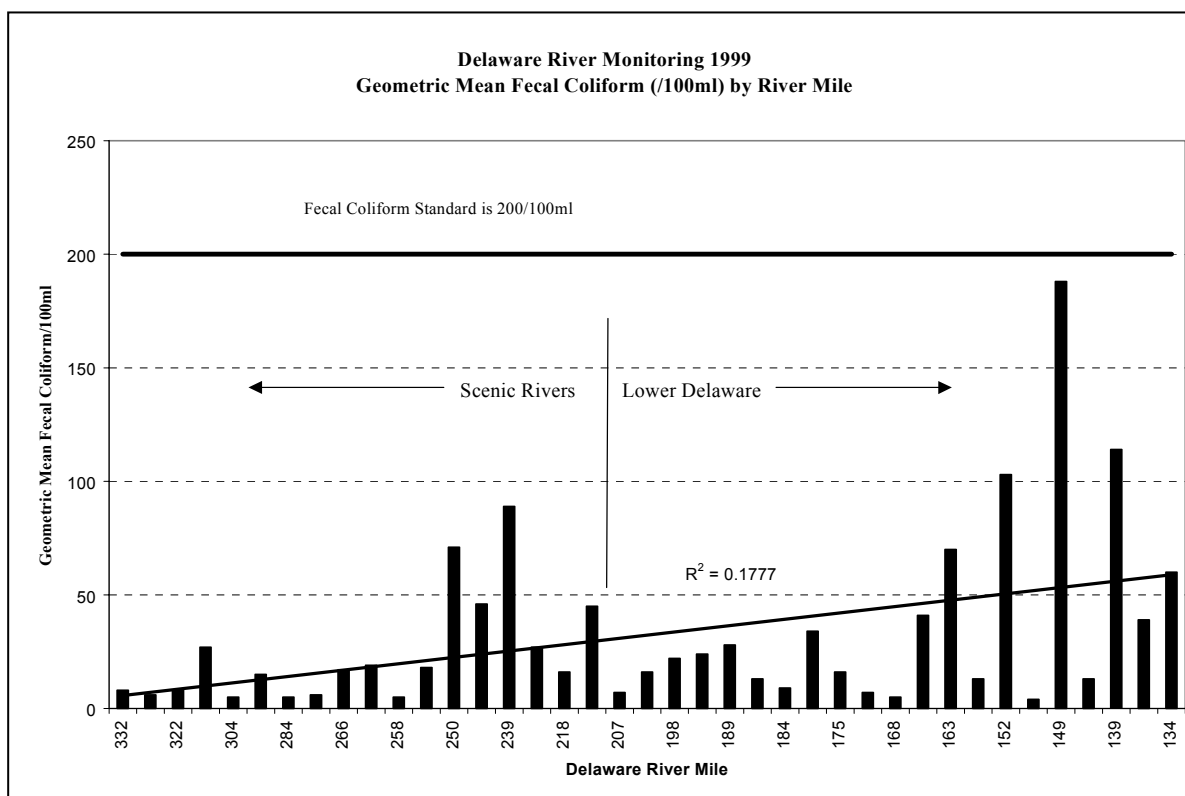


Figure 9.

Delaware River geometric mean fecal coliforms, Hancock, NY to Trenton, NJ (n=3 to 6, depending on site). No violation of the 200/100ml standard occurred, though three locations exceeded 100/100ml. Note the poor regression coefficient for trend analysis. Increased sampling frequency is necessary to reduce data variability and reveal potential spatial and temporal trends.

Statistical Comparison - Delaware River main Channel vs. Near Shore Fecal Coliforms

Student T-Test comparison of logarithmically transformed fecal coliform counts in Delaware River near-shore samples (n=65) versus main-channel samples (n=95) revealed that fecal coliform counts were significantly higher near the shore ($\alpha = 0.05$). Throughout the length of the Delaware River, near-shore fecal coliforms averaged 29/100 ml geometric mean, and main-channel fecal coliforms averaged 13/100 ml geometric mean.

The near-shore versus main channel comparison was repeated for three regions of the non-tidal Delaware River, the Upper Delaware (UPDE), Middle Delaware (DEWA), and Lower Delaware (LDEL). In the Upper Delaware, geometric means were universally low (8/100ml in the main channel, n=26; 9/100ml near shore, n=10), and no significant difference was detected. In the Middle Delaware, geometric mean fecal coliforms averaged 18/100ml (n=3) in the main channel, and 38/100ml (n=25) near shore, though data were too variable and few for a valid comparison. In the Lower Delaware, the difference became definitive and pronounced, averaging 16/100ml (n=66) in the main channel and 33/100ml (n=30) near shore. When accessing the Lower Delaware River, it is likely that higher fecal coliform densities will be encountered near the shore than in the main channel. Future monitoring designs must account for this difference.

Water Quality - Lower Delaware Tributaries

Figure 10 shows average dissolved oxygen concentrations measured from tributaries to the Lower Delaware River during summer 1999. Single-sample dissolved oxygen violations occurred at Jericho Creek, Bucks County, PA (DO 2.5 and 4.5 mg/l) and Warsaw Creek, Hunterdon County, NJ (DO 2.6 mg/l). In Pennsylvania, the minimum dissolved oxygen limit in Jericho Creek, which is designated a Warm Water Fishery (WWF) stream by PADEP, is 4.0 mg/l (Pennsylvania Code, Title 25, Chapter 93, Water Quality Standards, 1999). The same single-sample standard applies in New Jersey, where the NJDEP (Surface Water Quality Standards N.J.A.C. 7:9B, as of April 1998) classifies Warsaw Creek as a FW2-NT (Fresh water, non-Pinelands, non-trout waters). A possible oxygen depletion problem exists on Gallows Run, Bucks County, PA, where saturation values averaged 64% (n=3). No violations occurred, but saturation values were significantly lower than those observed in other study tributaries.

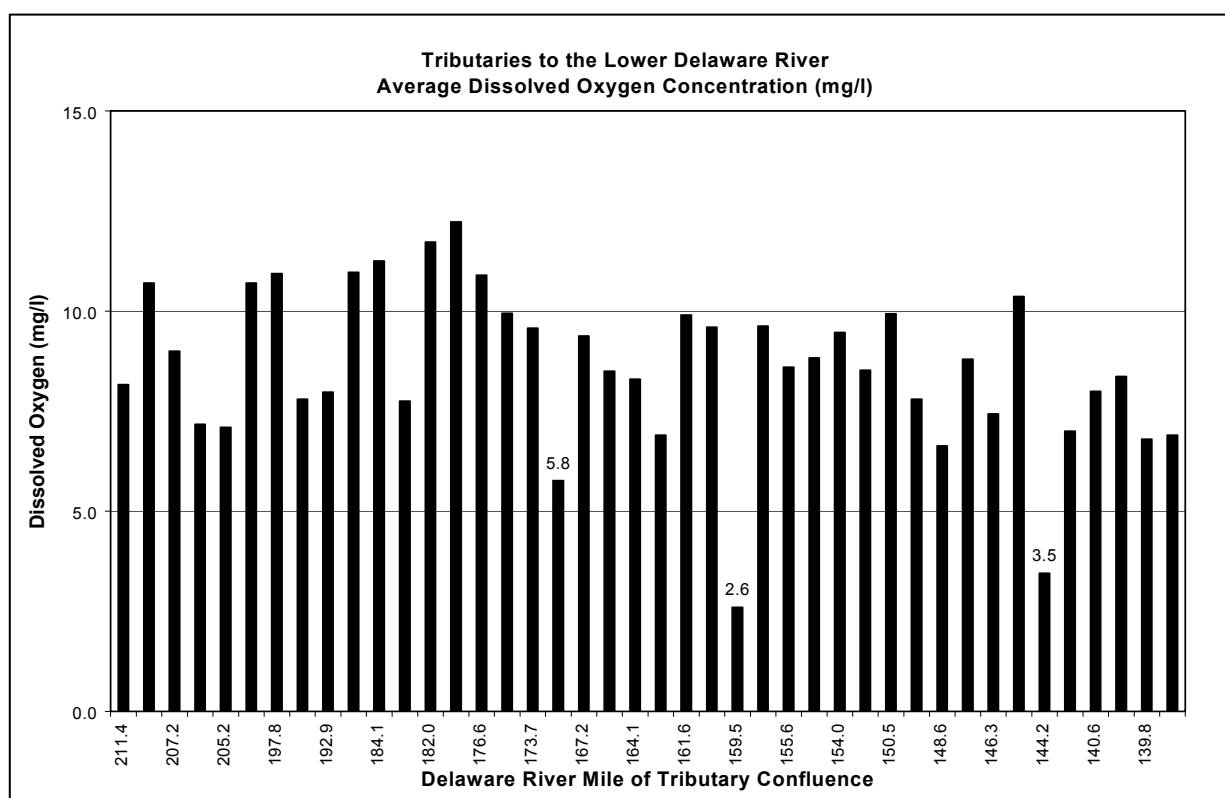


Figure 10.

Average dissolved oxygen concentrations measured from tributaries to the Lower Delaware River, June-August 1999. Single-sample dissolved oxygen concentrations below 4.0 mg/l were measured from Warsaw Creek, Hunterdon County, NJ (2.6 mg/l), and Jericho Creek, Bucks County, PA (2.5 and 4.5 mg/l, avg. 3.5 mg/l). Gallows Run, Bucks County, PA, (avg. DO 5.8 mg/l, n=3) displayed DO saturation values (68%) below most Lower Delaware River tributaries, which collectively averaged 104% DO saturation.

Some tributaries displayed unusually high or low conductivity. Mean conductivity of Lower Delaware tributaries was 295 $\mu\text{mhos/cm}$. An unusually high or low value was judged by whether or not the average conductivity for a particular tributary was outside one standard deviation around the reach-wide mean. Unusually low conductivity ($\mu\text{mhos/cm}$) was found in four tributaries to the Lower Delaware: Dunnfield Creek, NJ (38), Harihokake Creek, NJ (158), Lockatong Creek, NJ (169), and Moore Creek, NJ (144). Unusually high conductivity was

found in three tributaries: the Paulins Kill (455), Pequest River, NJ (445), and Bushkill Creek in Easton, PA (792). Origins of these high or low conductivity values may be natural (geologic) or anthropogenic. Speculation as to origin of extreme values is unwarranted given the limited data set. Each of these tributaries has been marked for further evaluation during future sampling investigations. Figure 11 shows average conductivity values for all Lower Delaware tributaries.

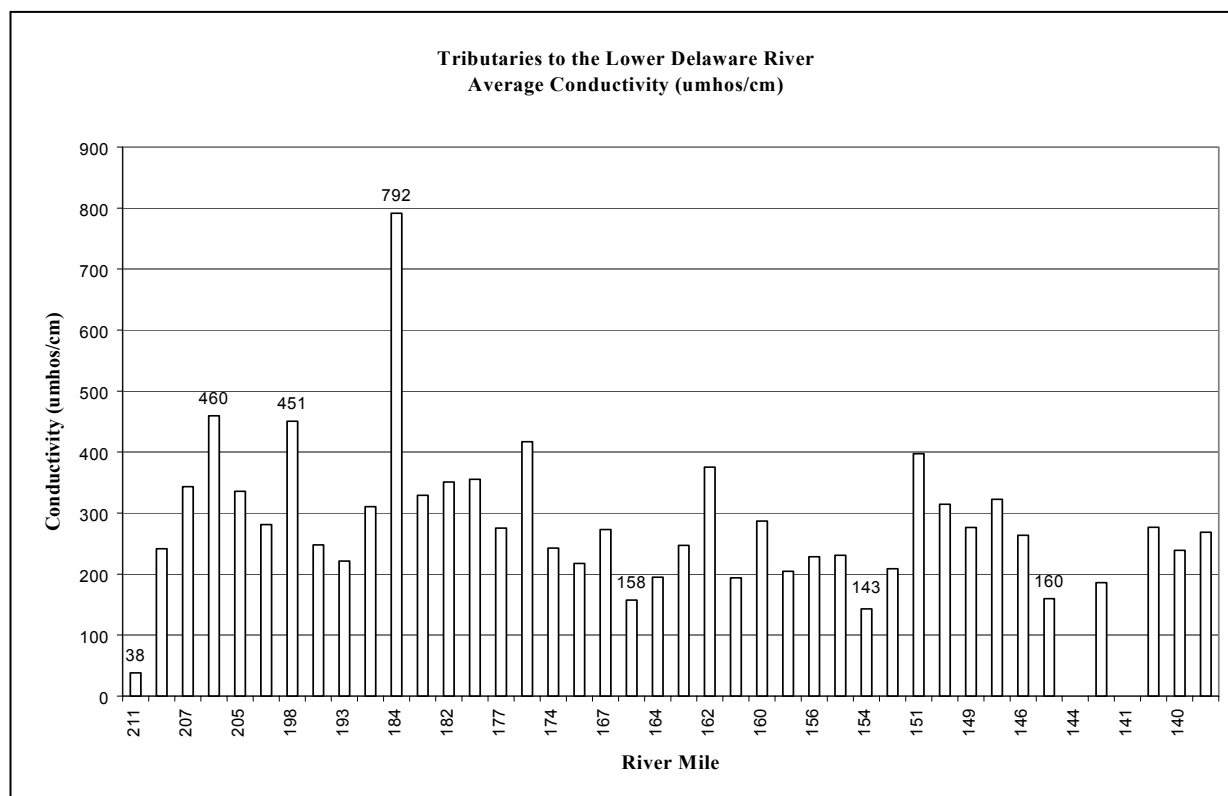


Figure 11.

Average conductivity of Lower Delaware tributaries (n=3). Unusually low and high values are labeled, noting tributaries' average conductivity outside one standard deviation around the reach-wide mean of 295 $\mu\text{mhos/cm}$.

Fecal Coliform Bacteria - Tributaries to the Delaware River

Among tributaries to the Delaware River, five Pennsylvania streams and six New Jersey streams exceeded the fecal coliform standard of 200/100 ml (Table 3). See Appendices C (raw data) and D (summary data) for fecal coliform counts in tributaries of the Lower Delaware River. Some streams listed in Table 3 presented additional water-quality problems, including low dissolved oxygen, high enterococcus densities, high pH, and high nutrient concentrations.

In tributaries where fecal coliform pollution was not observed, some displayed other water-quality problems. As mentioned previously, Cain's Run (AKA Warsaw Creek) and Jericho Creek showed very low dissolved oxygen concentration and saturation.

Table 3.

Fecal Coliform concentrations above 200/100ml during summer 1999. (Valid application of data to statistical requirements and measurement against standards would require 5 samples within a 30-day period. We did not achieve this sampling intensity. Geometric mean values are based upon, at most, 3 samples within a 60-day period).

Pennsylvania Lower Delaware Tributaries				
River Mile	Tributary Name	n = # samples	Geometric Mean FC/100ml	Other Observations
138.00	Buck Creek, Bucks Co.	3	709	high enterococcus
140.60	Houghs Creek, Bucks Co.	1 (single sample)	740	high enterococcus
144.20	Jericho Creek, Bucks Co.	2	1,885	low DO, high enterococci
184.10	Bushkill Creek, Northampton Co.	3	383	high conductivity, nutrients, entero.
190.58	Martins Creek, Northampton Co.	3	230	high enterococcus
New Jersey Lower Delaware Tributaries				
140.50	Jacobs Creek, Mercer Co.	3	344	high pH, enterococcus
143.20	Fiddlers Creek, Mercer Co.	2	340	high enterococcus
148.60	Swan Creek, Hunterdon Co.	3	273	high enterococcus
177.40	Pohatcong Creek, Warren Co.	3	878	high nitrates, enterococcus
197.40	Pophandusing Brook, Warren Co.	3	544	high enterococcus
205.20	Delawanna Creek, Warren Co.	3	446	high enterococcus

Statistical Comparison - Fecal Coliform Densities in Large Rivers vs. Small Streams.

Comparisons using t-tests of fecal coliform samples taken from large streams (drainage area >200 sq. km., geometric mean 22/100ml, n=199) versus small streams (geometric mean 73/100ml, n=151) revealed significant difference in mean values between the two data sets. This suggests that dilution in large streams, or perhaps shading of bacteria-killing UV light by canopy cover in small streams, significantly affects fecal coliform densities. Many tributaries exceeded 200/100 ml, while Delaware River densities remained well below the threshold.

Fecal coliform samples from large rivers versus small streams were compared by Delaware River region. The Upper Delaware small streams averaged 22/100ml (n=25), and large rivers averaged 9/100ml (n=48), and significantly differed using the t-test ($\alpha = 0.05$), though fecal coliform densities were universally low compared to the Middle and Lower Delaware. Middle Delaware small streams averaged 63/100ml (n=29), and large rivers 46/100ml (n=37), but no significant difference was found by t-test ($\alpha = 0.05$). In the Middle Delaware, fecal coliform densities remain low. In the Lower Delaware, small streams averaged 104/100ml (n=97), and large rivers averaged 25/100ml (n=114), a significant difference ($\alpha = 0.05$). In the Lower Delaware region, fecal coliform pollution is more pronounced in streams possessing drainage areas of less than 200 square kilometers than in larger rivers. Small streams within the Lower Delaware region are more likely to be impacted by fecal coliform pollution.

Comparison - Population Density versus Fecal Coliform Density

Fecal coliform densities from the three regions' (Upper, Middle, and Lower Delaware) small (drainage area <200 km²), large (drainage area > 200 km²), and combined streams were compared with regional 1990 population density (U.S. Department of Commerce, Bureau of the Census) apportioned to watershed areas within the regions. No relation was found (by scatter

plot) between fecal coliform density and watershed area. However, a relationship was observed between fecal coliform density of small streams and regional population density. Table 4 shows geometric mean fecal coliform density, drainage area, population, and population density for the three regions. A relationship exists between small streams' fecal coliform density and regional population density in drainage areas of less than 80 square miles (207 square kilometers). Figure 12 suggests that fecal coliforms may be useful as an indicator of urbanization in small watersheds. Future regional studies should be broken into study units of less than 80 square miles for maximum ability to track urbanization using fecal coliforms as an indicator.

TABLE 4.

Fecal coliform density, drainage area, and population of the Upper, Middle, and Lower Delaware River Basin. See Figure 12 for graphical relationships. From the Upper to the Lower Delaware, all fecal coliform densities differed using t-tests, except for all vs. small stream comparisons between the Middle and Lower Delaware.

	Upper (UPDE)	Middle (DEWA)	Lower
<u>(LDEL)</u>			
FC geo. mean, all streams	13 (n=73)	53 (n=66)	48 (n=211)
FC geo. mean, large rivers	9 (n=48)	46 (n=37)	25 (n=114)
FC geo. mean, small streams	22 (n=25)	63 (n=29)	104 (n=97)
Sq. mi. drainage area (in-reach)	1,557	740	2,610
Sq. km drainage area (in-reach)	4,033	1,917	6,760
Population 1990 (Census)	172,345	176,628	891,147
People / sq. mi.	111	239	342
People / sq. km.	43	93	132

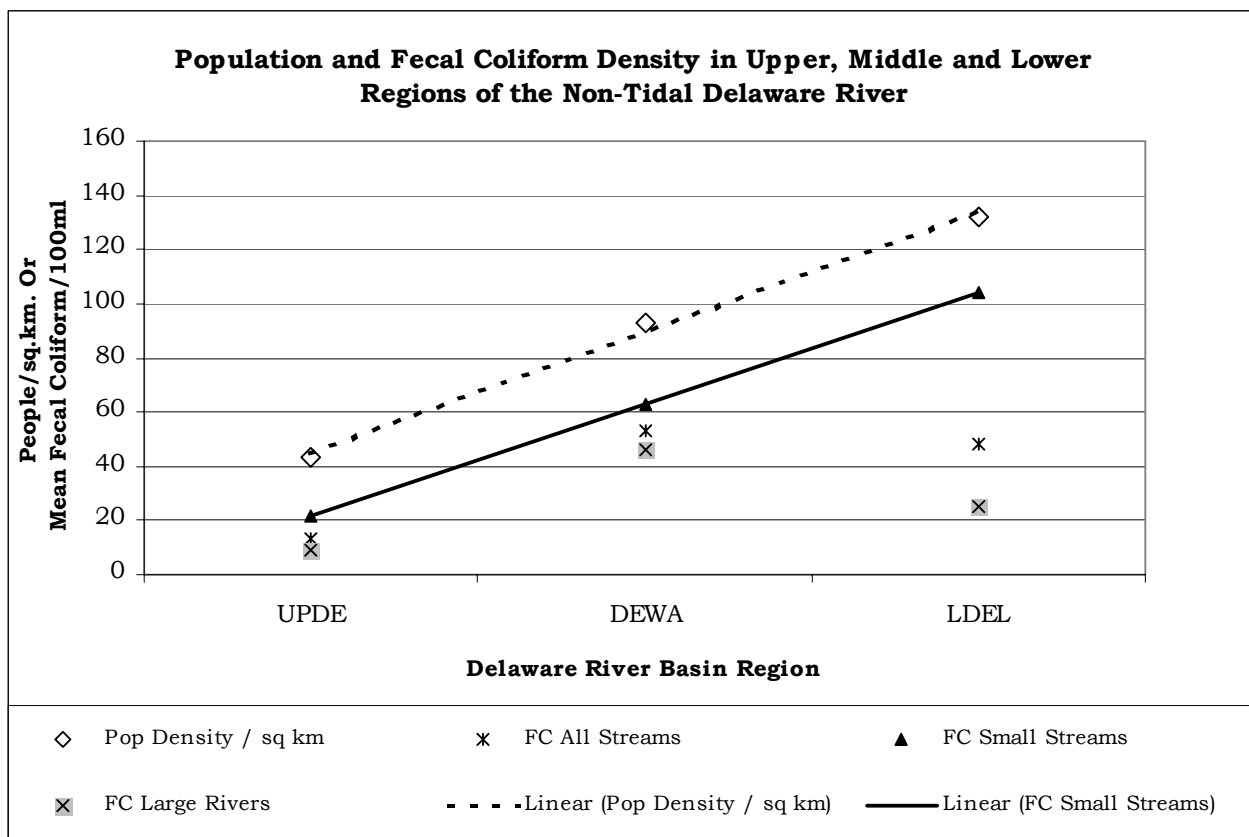


Figure 12.

Fecal coliform geometric means and people per sq. kilometer in the Upper, Middle, and Lower Delaware (number of samples are listed in Table 4). The small streams trend line and population density trend line did not significantly

differ for similarity of slopes. Population density may predict fecal coliform density in smaller watersheds.

Fecal Coliforms - Comparison with 1987 DRBC bacteria survey

The summer 1987 bacteria survey, like the 1999 survey, was an intensive effort designed to develop a baseline for assessment of water-quality changes, locate water-quality problems in the Delaware River, and recommend water-quality management actions (DRBC, 1988). In 1987, problem identification was based on comparison of fecal coliform results with the 200/100ml standard. The 1987 survey also measured *E. coli* and fecal streptococci. The 1999 survey sampled both fecal coliforms and enterococci. Although enterococci are a subgroup of fecal streptococci, the two cannot be compared with one another, due to interference by other members of the fecal streptococcus group. Comparison of 1987 to 1999 results is thus based upon fecal coliform results alone.

In 1987, two fecal coliform problem areas were discovered on the Delaware River in the vicinity of Wy-Hit-Tuk access (along the Pennsylvania shore below the Easton, PA sewage treatment plant), and Kingwood access (along the New Jersey shore below the Frenchtown, NJ sewage treatment plant). Remedial action was taken by state agencies, and upstream treatment plants have since improved the quality of their discharge. No such problems were found in 1999.

In addition, the 1987 survey found elevated fecal coliforms in a number of tributaries. This result was similar to that found in 1999. Table 5 displays 1987 and 1999 geometric mean fecal coliform densities for each tributary displaying elevated fecal coliform levels. In 1987, 14 more creeks exceeded the standard than in 1999. The magnitude of 1987 concentrations was generally greater than those found in 1999, indicating a slight improvement in bacterial water-quality from 1987 to 1999. Five creeks had higher fecal coliform average concentrations in 1999 than 1987, and these are shown in bold print in Table 5. The 1999 drought may have had some effect on this comparison, as precipitation and flow differed. Many streams sampled repeatedly in 1987 were dry in 1999. It is recommended that further and more detailed study be conducted of those waterways exceeding the standard in both 1987 and 1999.

Table 5.

Fecal Coliform concentrations above 200/100 ml, summer 1987 versus 1999. Counts are expressed as geometric mean density per 100 ml. (Valid application of data to statistical requirements and measurement against standards would require 5 samples within a 30-day period. Neither survey achieved this sampling intensity. Geometric mean values are based upon, at most, 3 samples within a 60-day period). **BOLD** print denotes creeks with higher fecal coliform concentrations in 1999 than 1987.

Pennsylvania Lower Delaware Tributaries			
River Mile	Tributary Name	1999 FC/100ml	1987 FC/100ml
138.00	Buck Creek, Bucks Co.	709 (n=3)	1636 (n=2)
139.70	Dyers Creek, Bucks Co.	< 200	602 (n=3)
140.60	Houghs Creek, Bucks Co.	740 (n=1)	580 (n=2)
144.20	Jericho Creek, Bucks Co.	1885 (n=2)	1360 (n=3)
146.30	Pidcock Creek, Bucks Co.	< 200	224 (n=4)
148.50	Aquetong Creek, Bucks Co.	< 200	1264 (n=3)
173.70	Cooks Creek, Bucks Co.	< 200	340 (n=1)
176.60	Fry's Run, Bucks Co.	< 200	1019 (n=5)
184.10	Bushkill Creek, Northampton Co.	383 (n=3)	2631 (n=4)
190.58	Martins Creek, Northampton Co.	230 (n=3)	820 (n=5)
207.30	Jacoby Creek, Northampton Co.	< 200	400 (n=1)
New Jersey Lower Delaware Tributaries			
133.80	Assunpink Creek, Mercer Co	no survey	5589 (n=4)
140.50	Jacobs Creek, Mercer Co.	344 (n=3)	212 (n=2)
143.20	Fiddlers Creek, Mercer Co.	340 (n=2)	397 (n=2)
145.20	Moore Creek, Mercer Co.	< 200	737 (n=2)
148.60	Swan Creek, Hunterdon Co	273 (n=3)	409 (n=3)
149.50	Alexauken Creek, Hunterdon Co.	< 200	477 (n=7)
152.50	Wickecheoke Cr., Hunterdon Co.	< 200	1739 (n=2)
164.10	Nishisakawick Cr., Hunterdon Co.	< 200	460 (n=1)
174.60	Musconetcong Riv, Hunt/Warren	< 200	663 (n=2)
177.40	Pohatcong Creek, Warren Co.	878 (n=3)	812 (n=2)
182.00	Lopatcong Creek, Warren Co.	< 200	4606 (n=2)
192.90	Buckhorn Creek, Warren Co.	< 200	429 (n=2)
197.40	Pophandusing Brook, Warren Co.	544 (n=3)	no survey
197.80	Pequest River, Warren Co.	< 200	775 (n=6)
205.20	Delawanna Creek, Warren Co.	446 (n=3)	500 (n=1)
207.00	Paulins Kill, Warren Co.	< 200	3300 (n=1)

Enterococci - Delaware River and Lower Delaware Tributaries

On the Lower Delaware River, the federal enterococcus guideline (and NJ standard) of 33/100ml was exceeded at Stockton Bridge (geometric mean 54/100ml), though this average was pushed over 33 by a single very high value (4540/100ml on 7/27/99, taken from the NJ side of the main channel). The source of this enterococcus bacteria is unknown. Figure 13 shows mean enterococcus densities observed on the Lower Delaware River during summer 1999.

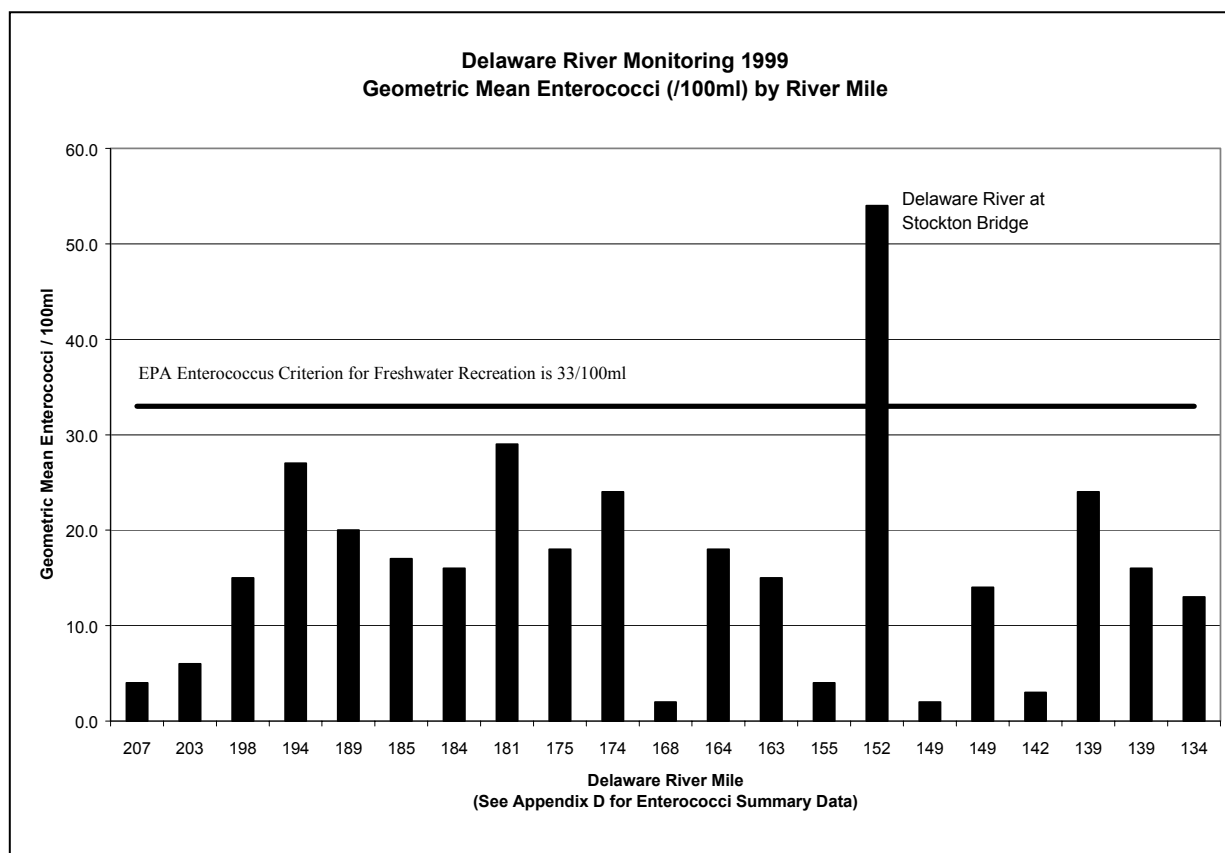


Figure 13.

Geometric Mean enterococci/100 ml for the Lower Delaware River, summer 1999 (n=3 at near-shore sites, n=6 at bridge sites). Source of the high value observed at Stockton Bridge, NJ-PA is unknown.

Table 6 lists tributaries where geometric mean enterococcus densities exceeded the federal guidelines (and NJ freshwater standard) of 33/100ml. Pennsylvania does not use enterococci for their standards, and like DRBC continues to use only fecal coliforms. Judging by the lengthy list of tributaries exceeding federal guidelines, use of the enterococcus standard might substantially expand the list of impaired waters, as tributaries with enterococcus densities exceeding the 33/100 ml federal guideline were more numerous than tributaries exceeding the 200/100 ml fecal coliform standard. Future investigations should include source-tracking studies of fecal coliforms, enterococci, and perhaps *E. coli*.

Table 6.

Enterococcus concentrations above federal guideline and NJ freshwater standard of 33/100ml, summer 1999. (Sampling intensity required for valid application of data to standards is 5 within a 30-day period. DRBC did not meet this frequency. Geometric mean values are based upon, at most, 3 samples within a 60-day period).

Pennsylvania Lower Delaware Tributaries			
River Mile	Trib Name	Geometric Mean Enterococci/100ml	n = # of samples
138.00	Buck Creek, Bucks Co.	675	3
139.80	Dyer Creek, Bucks Co.	135	3
140.60	Houghs Creek, Bucks Co.	960*	1 (*single sample)
144.20	Jericho Creek, Bucks Co.	600	2
146.30	Pidcock Creek, Bucks Co.	122	3
148.50	Aquetong Creek, Bucks Co.	101	3
155.60	Paunacussing Creek, Bucks Co.	47	3
161.60	Tinicum Creek, Bucks Co.	82	3
171.80	Gallows Run, Bucks Co.	112	3
173.70	Cooks Creek, Bucks Co.	105	3
176.6	Fry's Run, Northampton Co.	405	3
184.10	Bushkill Creek, Northampton Co.	128	3
190.58	Martins Creek, Northampton Co.	57	3
199.76	Allegheny Creek, Northampton Co.	219	3
207.2	Jacoby Creek, Northampton Co.	421	3
209.58	Slateford Creek, Northampton Co.	171	3
New Jersey Lower Delaware Tributaries			
140.50	Jacobs Creek, Mercer Co.	413	3
143.20	Fiddlers Creek, Mercer Co.	671	2
145.20	Moore Creek, Mercer Co.	131	3
148.60	Swan Creek, Hunterdon Co.	970	3
149.50	Alexauken Creek, Hunterdon Co.	61	3
152.50	Wickecheoke Creek, Hunterdon Co.	64	3
159.50	Caine's Run (Warsaw Creek), Hunterdon Co.	144*	1 (*single sample)
160.50	Warford Creek, Hunterdon Co.	300*	1 (*single sample)
164.00	Little Nishisakawick Creek, Hunterdon Co.	52*	1 (*single sample)
165.70	Harihokake Creek, Hunterdon Co.	150	2
167.20	Hakihokake Creek, Hunterdon Co.	42	3
174.60	Musconetcong River, Hunterdon/Warren Co.	94	3
177.40	Pohatcong Creek, Warren Co.	202	3
182.00	Lopatcong Creek, Warren Co.	473	3
192.90	Buckhorn Creek, Warren Co.	564	3
197.40	Pophandusing Brook, Warren Co.	636	3
197.80	Pequest River, Warren Co.	78	3
205.20	Delawanna Creek, Warren Co.	780	3
211.40	Dunnfield Creek, Warren Co.	135	3

Conclusions and Recommendations

1. Bacterial water-quality has apparently improved since 1987, considering the fecal coliform standard alone. Both the Delaware River and its tributaries showed improvement in fecal coliform densities measured from 1987 to 1999, though the 1999 drought may have affected this comparison, because there were fewer storm and runoff events in 1999, while the 1987 survey was conducted under normal hydrologic and climatic conditions.
2. This study should be repeated periodically (every 5 years is suggested), and sampling frequency should meet requirements for statistical validity at each site.
3. Fecal coliform and enterococcus density is greater in near-shore areas of the Delaware River than in the main channel, though very low levels were observed in most areas of the Delaware River.
4. Fecal coliform density may have been affected by dilution in the Delaware River and large tributaries, and by shading of UV light penetration in small tributaries.
5. A relationship was observed between population density and fecal coliform density, and was best observed in streams possessing a watershed size of less than 80 square miles (200 square kilometers). Fecal coliforms are valuable as general water-quality indicators, and provide a tool to follow effects of urbanization.
6. In future study designs, large tributaries should be broken into study units of 80 square miles or less, enabling study of population growth versus water-quality at an increased level of resolution for resource management decisions.
7. Enterococci appear to be more sensitive a measure of bacterial water-quality than fecal coliforms. Use of the enterococcus criterion would lead to a greater number of water bodies listed as impaired in Section 305(b) reports. Thirty-five tributaries contained enterococcus densities above the federal guideline and the New Jersey standard, as opposed to eleven tributaries where fecal coliform density exceeded standards.
8. Pending additional sampling and variability assessments, DRBC should consider establishing enterococcus standards for the non-tidal Delaware River, based upon either federal criteria or existing water-quality.
9. Enterococcus and probably *E. coli* should be tested in DRBC's suite of basic water-quality parameters, measured as part of the Lower Delaware fixed monitoring network. Fecal coliform testing already is part of the Scenic Rivers Monitoring Program, and that program might consider enterococcus testing for its parameter list.
10. The Delaware River exhibits periods of oxygen super-saturation and high pH. This may be caused by excessive aquatic plant growth, possibly due to excessive nutrient inputs, especially during periods of stable and low flow when river levels and temperatures are favorable for aquatic plant production. Further evaluation of river nutrient dynamics may indicate the underlying cause.

11. The upper limit of DRBC's pH stream quality objective (pH 8.5), should be evaluated since it is inconsistent with the state standard of 9.0.
12. Three tributaries may be experiencing dissolved oxygen problems. Jericho Creek (Bucks County, PA) and Cain's Run AKA Warsaw Creek (Hunterdon County, NJ) displayed concentrations below dissolved oxygen standards. Gallows Run (Bucks County, PA) displayed lower than normal dissolved oxygen saturation values. These tributaries, at the least, should be investigated in greater detail by the states, DRBC, or a combination thereof. Solutions to repeated water-quality problems should be implemented with cooperation of other agencies, non-governmental organizations, and local residents.
13. The Delaware River presently exhibits lower densities of fecal coliforms and enterococci than tributaries. Other relatively bacteria-free Lower Delaware waters include the Lehigh River, Tohickon Creek, and Paulins Kill. Based on our very limited observations, these waters may be acceptable for primary contact recreation. Verification of primary contact suitability should include toxicity as well as bacterial testing.
14. A fixed network of water-quality monitoring sites was established, and approximately 2200 data were collected from 74 sites. These data contribute to a long-term data record for the Lower Delaware River corridor, which will contribute to a management approach that prevents degradation of this portion of the Delaware River, and assists in protecting the water resources of tributary watersheds. These objectives would fulfill the goals outlined in the Lower Delaware Management Plan.

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










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


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